GÁSPÁR ALBERT

METHODS OF CONSTRUCTING AND VISUALIZING 3D GEOLOGICAL MODELS FROM THE GIS APPROACH

Thesis of Ph.D dissertation

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1 Introduction

The aim of geological studies is to collect information from the geological formations and features underground (raw materials, water, caves, etc.), and starting from this information, to predict the geological parameters of those localities, where direct observations are absent. Traditionally we use: 1) geological maps, where the primary data is from the outcrops; 2) geological cross-sections, where information originates from the surface data, and from borehole logs or geophysical measurements. The spatial point of view is an important "tool" for a geoscientist. That's why the geological maps and cross-sections were drawn up in many cases as block diagrams in axonometric view even before the information revolution. At that time, just as today, people made geological models to visualize spatial information in a more picturesque way than the 2D methods (ALBERT 2005/a).

Geologists use thematic cartography to visualize the spatial relations of the gathered geological knowledge. When elaborating a geological map, we have to use tools of modern informatics to be able to disseminate our cartographic material on popular channels like the internet. So a modern geological map is a digital and "intelligent" map with GIS background. Although most people prefer paper maps, we have to note that the maximal functionality of these thematic maps can be reached only on computers. It's the same with geological maps also; most geologist use paper maps and the contributors draw on paper if they work on a map, but insisting on the "paper paradigm" bounds the hands of the geologists. The visualization of geological maps on the monitor of a computer opens up the possibility of new dimensions (i.e. TURCZI ET AL. 2004), but these are already called geological models; and looking on a model from the top view we'll see the geological map itself.

The knowledge base of the geological exploration of Hungary is the Geological Institute (MÁFI), which had archived a considerable amount of mapping and drilling data of the country during its 140[1] years. A new interpretation of the mapping data had been finished in 2005. The result is the 1:100 000 scale map series, the "Unified Geological Map of Hungary" (EOFT-100). This project had unified the indexing method of the geological legend on all the digitalised maps and in the well-log databases, which contain more than 43 000 boreholes. This unification was necessary for creating 3D models. Starting from the results of this project, I planned to work out new effective methods of modeling, concentrating on active explorations as pilot projects.

[1] It's predecessor the Royal Institute of Geology was founded in 1869.

2 Aims

As a geoscientist of the Geological Institute of Hungary I experienced that construction of a 3D geological model is a very time consuming work, which requires cartographical, geological and information technological knowledge, and it's most important phase is the design of the data structure. That's why my aim was to work out tenets of system planning regarding the 3D geological modeling, which optimize the use of resources (time, material and personal) during model building and servicing. To achieve this I applied these tenets to the ongoing projects, and kept my eyes on the consequences.

During the research my aim was to study the general conditions, the know-how and the best-practices of 3D geological models through practical applications, and to work out new methods if necessary. My further aim was to get to know the tools of informatics of the computer modeling and to identify the basic criteria for the quick and handy 3D modeling applications in general by using them.

Scientific works (like geological maps and block diagrams) of all era would reach both the scientific and public community easier, if they're in a popular, visually enhanced form of that era (i.e. GROSHONG 1999). Because of this, I studied the methods of visualizing geological information either in 2D, or in 3D. In my publications I emphasized that the visualization of 3D geological models must not be suppressed because of technical conditions. A picturesque form of the geological information makes it more valuable for people, and on the long run it makes geosciences more interesting for the public.

3 Applied methods

Recently there is no real 3D modeling system amongst the tools of informatics of the Geological Institute of Hungary. Tools, which are used for creating 3D geological models, have limited capability, or the database connections are not entirely manageable from the developer's interface. This situation was rather worse at the time, when I started my research. That's why, in order to study a working 3D model, first I had to create one. The ongoing digital archiving of geological observation maps, and the project of reviewing the archive well-log database (GYALOG ET AL 2002), served as a perfect opportunity for this. Partly for quickening the work, I built up an AutoCAD based GIS from the digitalized maps and well-logs of the Vértes Hills and Gerecse Mts. area.

During the research I touched on the study of the technological line of model construction, which principles are independent from the modeling environ. In order to handle the data with the widest point of view during modeling, I took part in all steps of the technological line –

starting from the data collection on the field, through the design and construction of the data structure, until the processing and interpretation of the data – and (if it was necessary) I taught the methodology to the colleagues.

I studied the methods of fieldwork during the geological mapping of the Vértes Hills and Gerecse Mts. and during both the surface (drilling) (ALBERT 2003) and the subsurface (tunneling) exploration phase (ALBERT ET AL. 2006) of the project of designating a disposal site for low and intermediate level radioactive waste in Bátaapáti, ongoing since 1996. The data collecting methods were basically the following:

- Field trips using paper maps and satellite navigation;
- Logging and noting manually in paper notebooks, and digitally in PDA-s (Personal Digital Assistants = handheld computers).

During the design of the data structure I sorted the basic data into three groups:

1. Maps, which were usable for creating mapping database.
2. Borehole data, which were stored in database and can be searched by unified geological indexes.
3. Other materials (like descriptions of observation points, photos, sketches), which were organized in a controlled storage- and file system.

During the construction of the mapping database of the Vértes Hill and Gerecse Mts. area I acted on the unified indexing rules of the geological formations (GYALOG ED. 1996) and on the structure of other (index and borehole) database, which were already in use (GYALOG ET AL. 2005). The storage- and file system had also inherited partly the already used structure (ALBERT 2009), but in case of the newly created files, I used a strict naming rule.

After the processing and organization of data, I created 3D models using modeling proceedings. The modeling proceedings are the mathematical frame of the data processing, which are included in the modeling software in most cases. In my dissertation I touched on those proceedings in detail, which I developed and used software-independently. Amongst these, I firstly used the following methods in the field of 3D geological modeling:

- I unified the data processing methods in defining the parameters of different planar objects in large scale 3D geological models, using spherical geometry.
- I worked out a double projection method for creating tunnel wall-maps of observed geological features in mine-tunnels, using a spherical projection and a central cylindrical projection; this method is the first known practical application of the central cylindrical projection.

- I worked out a method for creating 3D volumetric models of caves, using the original point-survey data, and the archive 2D cave passage maps.

I worked out a new classification system for the 3D geological models, which describes all the varying type of models, which I studied, from the same geometric approach. The geometric approach makes it possible to sort the models according to the geometrical patterns and forms, which represent the geological information in the model space, and unifies also the raster, and the vector approaches of modeling.

In the geometric approach of model classification, I divided the 3D geological models into the following categories:

- Irregular models:
    - Models of one and two parameters (point clouds)
    - Models with three parameters (simple planes, vectors)
    - Surface models with irregular networks (TIN)
    - Models of irregular spatial objects (unique and tessellated bodies)
- Regular models:
    - Surface models with regular networks (grids)
    - Models of regular spatial objects (voxels)

In my research I used the most complex modeling methods (irregular and regular spatial objects) during the construction of the volumetric and porosity models of the Pál-völgy cave (JUHÁSZ ET AL. 2007), and described in the dissertation in detail.

4 Results (thesis list)

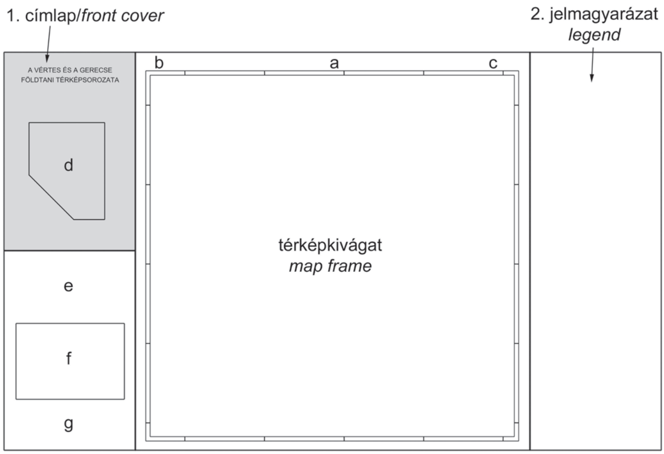
I. I worked out the objective criteria for the 3D modeling applications in general.

During my research I made effort to get to know the whole technological line of 3D geological modeling. As a result of this, I studied all the stages of "life" of the geological data in a 3D model from the genesis, through the processing, up to the visualization. These experiences helped me to observe the data with the widest point of view during the modeling, and to determine a list of criteria which is necessary to consider, when choosing a 3D modeling software (ALBERT 2003).

II. I worked out a method for the cartographical representation of archive geological field maps.

I considered all the observation maps and field notes of the Geological Institute of Hungary as authentic documents of primary data. My aim was to bring these data into an information system, which makes them quickly and easily accessible. To achieve this I created a GIS from the observation maps, which were in quite chaotic, inordinate state, as the elaboration were half ready, or even not started, and as they had different projection system (ALBERT 2009).

This system made it possible to create a database from the geological indexes of the processed maps after the harmonization of the thematic content with the neighboring map sheets and with the topography. With connecting the working GIS with the borehole database, and integrating the digital terrain model of the area, I achieved that I manage to run spatial analyses, to create geological cross-sections arbitrarily and to create surface model of the basement rocks in the region of the Vértes Hills and Gerecse Mts. This project was also suitable to study the general characteristics of the informatics of a large-scale geological model.



1. figure. Sketch of a digitally archived 1:10 000 scale map sheet of the Geological Map Series of the Vértes and the Gerecse Hills. Explanation: a = name of the sheet, b = type of the map (i.e. observation and covered geological map); c = grid; d = location map; e = colophon; f = list of lithological extensions of the geological indexes (table); g = reference (ALBERT 2009).

Besides the processing of the manuscripts of the mapping data, and inserting the maps into a GIS, I made effort to create ergonomically and cartographically correct layouts. As a result, I made colored, large scale maps containing the observed points and the geological formations. These layouts are useful both on the field and in the office since I worked out a method, the *selective reduction* of color channels, which made it possible to create maps, which can be used both as geological maps and for field navigation. The topographical content of these maps is similar with the topographic content of the maps, which were used during the fieldwork. The legends of these maps were created from the mapping database, using a Visual Basic application, and contain only those elements, which are present on the actual sheet. The code of the VB application was written by me.

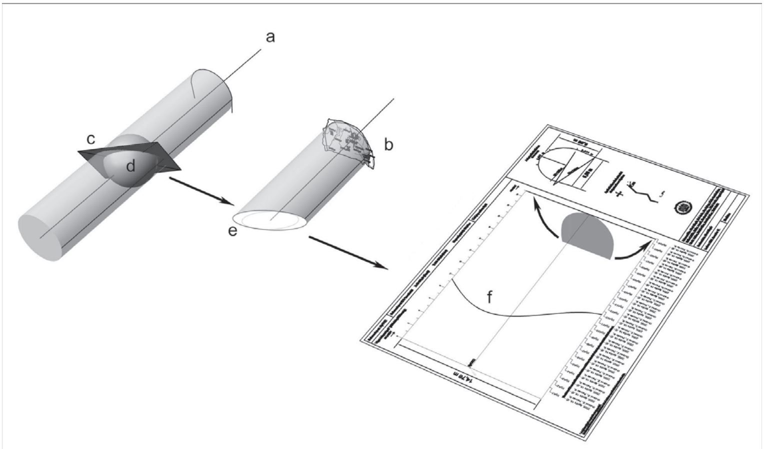
III. I made a proposal to sort the structural elements in tectonic formations, and worked out a system for the classification of tectonic elements in 3D geological models.

GIS processing of geological data revealed the problem that organizing the geological objects in a 3D model into a database concerns not only the different lithological categories, but the structural elements also, if great numbers of these elements are present in the modeling area. In a database of the 3D model we have to order a unique record (a key) to each object of the model, but if we'd like to create a useful data structure, these keys should be practical and didactic indexes. My observations of tectonic elements on the NE part of the Gerecse Mts. (ALBERT 2005/b) served as the base of a 3D model, where I worked out a method of indexing the tectonic elements in the database of the 3D geological models, and made a proposal to sort the structural elements in tectonic formations (ALBERT 2005/a).

IV. I unified the data processing methods in defining the parameters of different planar objects in large scale 3D geological models, using spherical geometry.

During the processing of the coordinate related data of structural geological elements and fitting the objects into 3D models, I had to compare data of variable form and amount in order to create a geological picture of the given area. These data are direction and dip values, which usually can be correlated with other structural geological data. The comparison makes it necessary to use spatial geometry in the computations. Since the most effective way of processing dip and direction values is the spheroidal geometry, which is commonly used in higher geodesy, I worked out and applied this mathematical approach to correlate data from different sources (i.e. surface outcrops, boreholes, tunnels) in the exploration project of the disposal site for low and intermediate level radioactive waste in Bátaapáti (ALBERT 2005/a).

V. I worked out a double projection method for creating tunnel wall-maps of observed geological features in mine-tunnels, using a spherical projection and a central cylindrical projection;



2. figure. Method of projecting of a planar object onto a map (ALBERT ET AL. 2006). Explanation: a = tunnel axis; b = tunnel front; c = measured plane; d = parametric sphere; e = 3D ellipsoid on the tubular model of the tunnel; f = projection of the plane.

In the same project in Bátaapáti, I worked out a double projecting method to create the maps of the wall surfaces of the exploration tunnels. The first step of the method was to create the projection of the documented plane, which was observed in the tunnel, on a sphere, where it formed a 3D circle; then I projected this circle onto a plane using the equations of the central cylindrical projection (ALBERT ET AL. 2006). This method is a good sample for the practical application of the central cylindrical projection.

VI. I worked out a method for creating 3D volumetric models of caves, using the original point-survey data, and the archive 2D cave passage maps.

The proceeding of a modeling depends on the original data, and in most cases it requires unique approach, to achieve the best results. This was concluded during the volumetric 3D modeling of the Pál-völgy cave, where I worked out a unique modeling process, which was based on the original point survey data, and the 2D maps of the cave (ALBERT 2008). The modeling included the simulation of the secondary porosity of the rock body, which surrounds the cave. Here we have managed to prove the rightness of the volumetric model, by using field observation methods (JUHÁSZ ET AL. 2007).

VII. I firstly published cartographic material and a review of the cartographic genre of "geological tourist maps" in Hungary; I introduced these maps as the 2,5D representation of a 3D geological model.

The visualization of 3D models was always important for me during my work. I classified the visualization method of 3D models regarding the type of media, and I defined the necessary criteria of it for each type. Figures, which were derived from 3D models were published not only in scientific, but in popular publications as well. I focused on the 2,5D cartographic representations of the geological models, including the genre of "geological tourist maps", which is primarily for public use. I firstly published cartographic material and a review of this kind of cartographic material in Hungary, and took care for the dissemination of this genre, as it is a possible "afterlife" of 3D models.

VIII. I worked out the idea of the GEOnukleus software, which would be able to visualize measurable data of 3D geological models through inter- and intranet with a client interface, and I led the project which worked out the use-case model of this application.

The analysis of models in a virtual space, would ease to reach a better understanding of the geological environ of a region. This paradigm will prospectively displace those methods, which are based on 2D visualizations on paper media. Recognizing this trend, I worked out the concept of an application (the GEOnukleus), which is independent from the modeling tools, but is able to visualize, and to perform 3D analyses of geological models through inter- and intranet. With other scientists, we worked out the use-case model of this application (ALBERT & GUSZLEV 2006). Our aim was to create a user interface for those people, who are not experienced in handling modeling software, but are interested in studying geological information in the virtual space.

Conclusion

The 3D geological modeling is an interdisciplinary science where, the modeling method depends on the quality and quantity of the original data, and in most cases it requires unique approach, to achieve the best results. In case of processing archive data the modeling method cannot influence the circumstances of data colleting, though it strongly depends on them but in active research phase the geological documentation and the 3D modeling are not separable processes although they are carried out on completely different locations. The circumstances of the documentation (the physical conditions, instruments, technologies) will determine how precise model we can create, while the mathematical proceedings of the modeling might require the recording of certain geological parameters with more emphasis.

Although the feature of 3D models is determined most strongly by the time and the financial conditions, the modeler has to aim for the best result, which, according to my experience, cannot be achieved without a well documented "handy" data structure. Therefore the most important phase of constructing spatial models is the design.

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